Volume 27 September, 1941 Number 9

Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

Aircraft Engine Lubrication

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LUBRICATION

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Aircraft Engine Lubrication

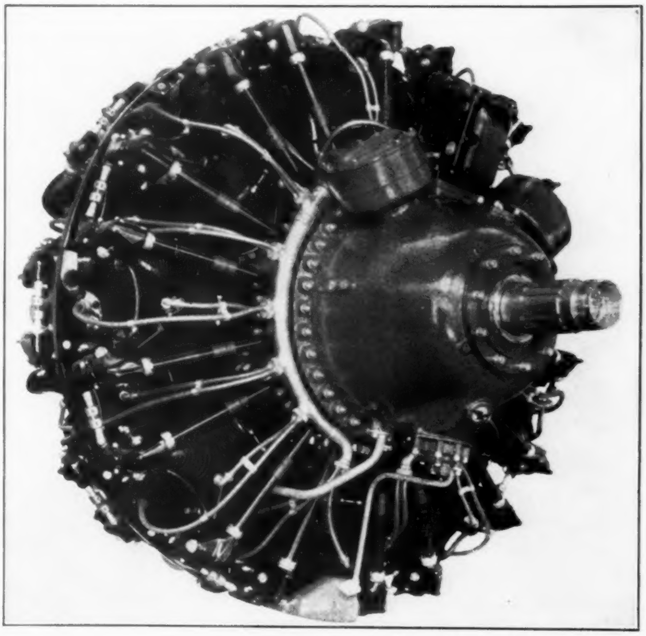
THE modern aircraft engine represents the achievements of cooperative research work by both engine designers and the petroleum chemist.

The progress made in engine design may be realized in comparing those used in military aircraft 25 years ago with the latest engines in use today. Engines of 180 h.p. using castor oil as a lubricant, and fuels of less than 60 octane rating, and requiring overhauls at 50 hour intervals, were characteristic of engines in the last war. In contrast, today we find engines of over 2,000 h.p. in use, lubricated with highly refined petroleum oils, consuming 100 octane fuels and capable of continuous operation for 700 hours between overhaul.

In the September 1940 issue of LUBRICATION it was shown that some of the increases in engine power tied in very closely with increased octane rating of fuels. In this issue lubrication will be discussed and an attempt made to show the very close connection between design, maintenance and operation with aircraft engine oils in the modern aircraft engine. Much of our data is based upon successful lubrication experience of about one and one-quarter million engine hours of scheduled airline operation as well as thousands of hours of light aircraft engine operation annually.

Piston Cooling and Lubrication

The piston of a high output aircraft engine is often regarded as the heart of the engine. This vital part must perform many functions and it can easily control the degree of success or failure in engine operation. The piston should be as light in weight as possible, yet strong enough



Courtesy Pratt & Whitney Aircraft

Fig. 1—Three-quarter front view of Pratt & Whitney Double Wasp Engine which develops 1850 h.p. at 2600 R.P.M.

to withstand enormous loads at high temperature, though at no time should it be allowed to run at temperatures high enough to cause ring sticking or carbon accumulation from oil on the underside.

Courtesy Wright Aeronautical Corporation

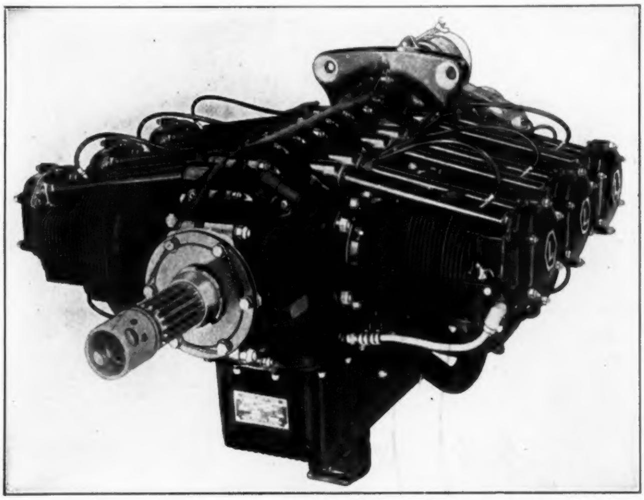
Fig. 2—Sectional view of Wright Cyclone cylinder series G-200 showing piston and valve details. This is an excellent example of the achievements in fin design of air cooled cylinders. The fin area on the head is 2.4 times greater than the earlier F model.

Heat absorbed by the head of the piston is dissipated in a number of different ways. Some of it passes out through the rings and cylinder and the balance is carried away by oil. It is interesting to note that the amount of heat which may be carried out through the rings is definitely limited. Consequently, in high output engines, a greater proportion of heat must be carried off by the oil than in lower output engines.

In the 1000-1200 H.P. class 1800 B.t.u. or more are carried away per minute by the oil. The proportion of heat imparted to the oil in terms of total heat rejection (excluding that lost in the exhaust) amounts to 11% to 25% in present high output engines. As power outputs continue to be boosted more and more, oil cooling of pistons will be necessary. For this reason adequate oil coolers are a necessity in such engines.

An accurate control of piston temperatures is tremendously important to avoid overheating and subsequent ring sticking and objectionable deposits. A variety of successful methods are used to cool pistons with oil. The general method is to spray oil against the underside from jets placed in the crankshaft. Of course, it is important to spray oil against the underside without flooding the cylinder walls, otherwise excessive oil consumption might follow. The Wright Cyclone G-200 series has a unique and very effective method of spraying oil to the pistons. Jets are placed in the counterweight assembly which pass by the piston when the latter is at the bottom of the stroke. In the Continental 4-cylinder horizontally opposed engine an effective method is used to cool pistons. Oil jets are placed in the bearing caps which direct an oil spray to pistons on the opposite bank in the bottom stroke position. The substantial reductions in piston temperature with this arrangement greatly reduced tendencies towards ring sticking. Uniflow pistons on Wright Cyclone engines utilize a large oil flow along the skirt for better cooling. Actually, the bottom ring on these pistons acts as an oil pumper to keep the skirt flooded and the scraper rings above the pin return the oil to the inside of the piston. This setup has effectively overcome scuffing of the skirt.

Airline experience has demonstrated again and again the importance of controlling piston temperature by oil cooling. It is not uncommon to find an occasional engine coming down for overhaul with dirty pistons, a few stuck rings and a heavy coating of carbon on the underside. These cases usually are the result of overheated pistons, caused by clogged oil jets in the crankshaft, or excessive oil flow in the accessory section and an insufficient amount in the power section. Maintenance personnel on



Courtesy Lycoming Division—Aviation Mfg. Corp.

Fig. 3—Three-quarter front view of Lycoming 6 cylinder horizontally opposed air cooled engine of 150 or 175 h.p. This type of engine is very popular in the smaller aircraft.

airlines have quickly appreciated how important it is to cut down the oil flow from miscellaneous bushings and supercharger impeller seals in order to deliver the maximum amount to the power section for good piston cooling.

One airline discovered recently that oil inlet temperatures can be too low for best results. By raising these temperatures from 120-145 degrees Fahr., piston cleanliness was greatly improved. Two reasons are believed to have given this improvement: first, higher rate of oil flow with less viscous oil at the higher temperature giving better piston cooling, and second, reduced clogging of oil jets from low temperature sludge. Of course, extremely high oil temperatures should be avoided since piston temperatures will also increase with increases in oil temperature in the range above 160 degrees Fahr. For these reasons we find that best results are obtained with oil temperature controlled within the range of 145 to 165 degrees Fahr. In some cases successful results are obtained with oil inlet temperatures up to 180 degrees Fahr. There is not enough service experience with higher oil temperatures to indicate the advisability of further increases, although it is believed that less satisfactory lubrication and cooling would follow as well as increases in engine deposits.

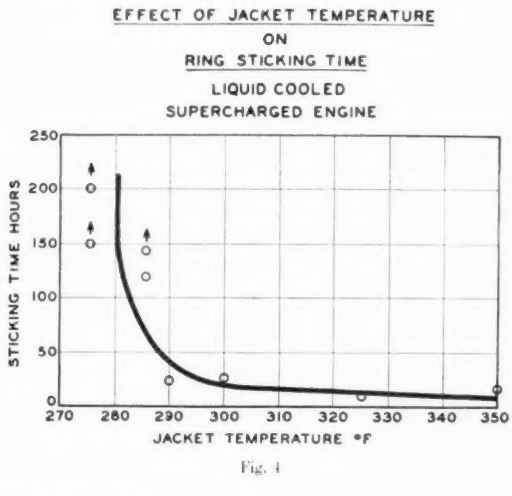
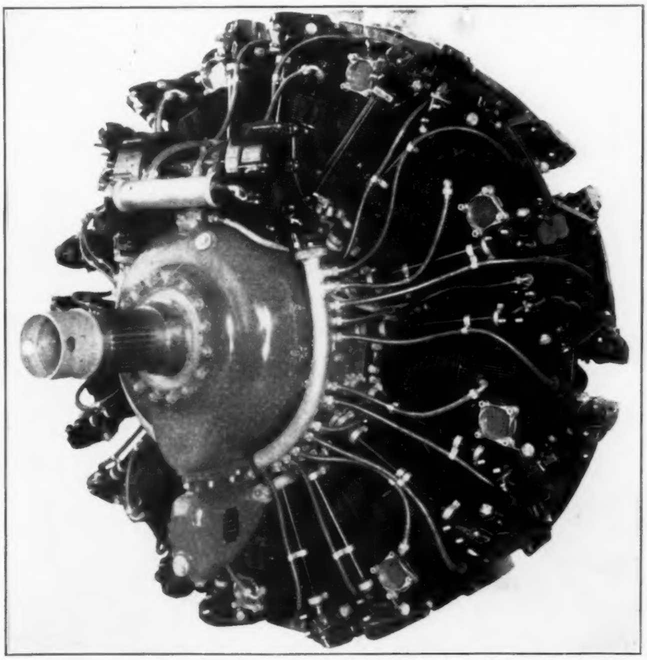


Fig. 4

Ring Design

Piston rings serve three primary functions in an engine; i.e., they seal against blowby, prevent excessive oil consumption, and aid in heat transfer from piston to cylinder. To perform each of these functions rings must always be free to seat properly and not clog or stick. From a lubrication angle freedom from ring sticking is extremely important. This is especially true in high output aircraft engines.



Courtesy Wright Aeronautical Corporation

Fig. 5—Three-quarter front view of the Wright Duplex Cyclone Engine developing 2200 h.p. at 2600 R.P.M.

Ring sticking may be influenced by any one of the following:

1. High ring belt temperature
2. Type of oil
3. Ring design
4. Rate of oil consumption
5. Ring side clearances.

While there is some difference of opinion regarding the true phenomenon of ring sticking, it is safe to say that in an aircraft engine it is usually caused by decomposition of oil at high temperatures to form a sticky substance which holds the ring clamped into the groove. After reaching the point where oil oxidation has begun the rate doubles and redoubles for each 20 degrees Fahr. increase in temperature. Therefore, any slight increase in temperature of the ring belt may easily account for the difference between a successful engine and one which shows prolific ring sticking. An interesting example of the importance of temperature on ring sticking appears in Fig. 4 as "The Relation Between Ring Sticking Time and Jacket Temperature." Note how rapidly ring sticking occurs with the higher jacket temperature.

Lubricating oil plays an important part in ring sticking; it is especially important in an engine which is inclined to be critical in this respect. Unfortunately, there is no test other than the full scale engine test which will predict this tendency in an oil; even oxidation stability as measured by various established tests offers no help in this connection either.

It should be noted that recent developments in additives have presented means for greatly reducing ring sticking tendencies of aircraft engine oils. Future improvements along these lines appear to be very promising.

The efforts of the engine designer in preventing abnormally high ring belt temperature together with recent improvements in aircraft engine oils are chiefly responsible for the excellent service records in high output engines used on airlines today.

Wide side clearances are helpful in reducing ring sticking. They are disadvantageous, however, in that greater blowby and increased possibilities of sludging from fuel soot, lead compounds, etc., as well as higher rates of oil consumption may develop. For these reasons maintenance personnel find it desirable to adhere to rather close minimum and maximum limits of ring side clearances.

One of the most interesting of the recent developments in piston rings is the wedge ring. This ring may have an included angle between the sides varying from 8 to 15 degrees or higher. It has a number of very worthwhile advantages when used as a compression ring in highly supercharged engines such as:

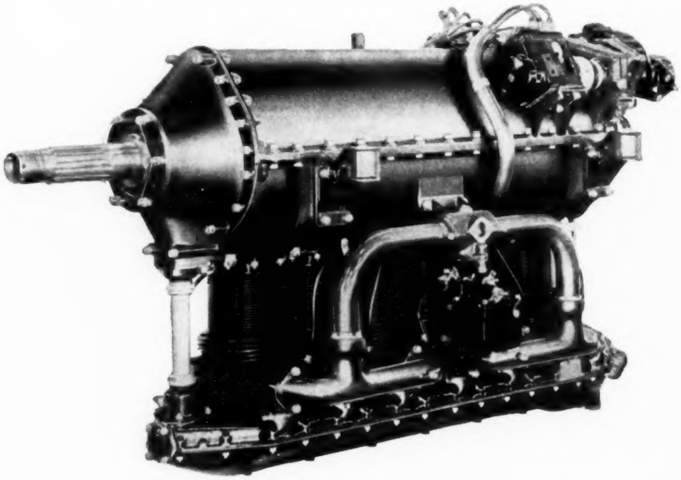
1. Less ring sticking.
2. Stronger ring lands.

Ring scuffing is another problem of ring lubrication that is requiring more attention in engines of high BMEP*. The point has already been reached in some high output engines where certain compounded oils show less ring wear, scuffing or feathering than do straight mineral oils. Millions of engine hours of airline service have proven that ring wear and cylinder wear can be reduced by use of suitable additives; as a result compounded oils are now accepted lubricants for some engines.

Bearings and Bearing Corrosion

Babbitt was considered unsuited as an aircraft engine bearing material many years ago. The demand for greater load-carrying capacity and higher fatigue resistance fostered the development of a number of other bearing metals such as copper-lead, lead plated silver, cadmium-silver, or cadmium-nickel alloys. These bearing metals have been meeting the requirements of master rods in radial engines and for connecting rods as well as main bearings in the in-line, "V," or horizontally opposed types.

From a lubrication angle these newer alloys are subject to corrosion which, incidentally, is not found with tin-base babbitt. Corrosion in aircraft engine bearings constitutes the loss of lead or cadmium which has gone into solution in the oil. Fortunately, bearing corrosion in this class of service is comparatively rare; a few possible reasons will be given later.



Courtesy Ranger Aircraft Engine Company

Fig. 6—Three-quarter front view of Ranger 6 cylinder inverted in line air cooled engine of 175 h.p. These engines are popular in training and private planes.

All oils oxidize when exposed to high temperatures in the presence of air for an appreciable length of time. Some will oxidize in a comparatively short time while others such as highly refined aircraft engine oils withstand exposure to high temperatures for longer periods. Organic acids form initially. Many of these materials will dissolve lead and cadmium. Certain mineral acids, on the other hand, such as sulfuric, do not affect lead. In addition not all types of organic acids either affect lead or cadmium.

In order to cause corrosion of these alloy bearings there must first be oil oxidation. An accurate control on temperature is therefore one of the most effective means of preventing oxidation and corrosion. This is clearly illustrated in Fig. 7 which shows effect of temperature on rate of bearing corrosion as determined on the MacCoull bearing corrosion machine. Refer to p. 107 for a discussion of

*BMEP—Brake mean effective pressure.

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this test. Briefly, this is a highly accelerated test designed to show differences in the corrosion tendencies of various oils. In addition to the effect of temperature it is evident that the longer an oil is exposed to high temperatures the greater will be the extent of oxidation. Oil consumption, strangely enough, plays an important role in this connection, and large

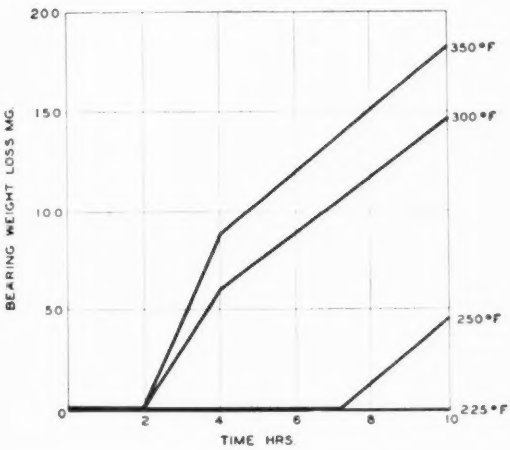


Fig. 7

additions of makeup oil prevent the buildup of oxidation products. Conversely, an extremely low rate of oil consumption means that a given quantity in a system is exposed for a greater number of hours to high temperatures. See Fig. 9. With a given engine in automotive service we also find that the greatest oxidation effects occur under conditions of the lowest oil consumption.

In aircraft engine service bearing corrosion is quite rare because the bulk of the oil is not oxidized appreciably. Good oil temperature control in addition to the large capacity of the tank and existing rates of oil makeup are important factors in this connection.

A tremendous amount of research work is currently being done on the study of improvements in oils to reduce oxidation and corrosion. Already many types of inhibitors and additives are effectively employed in automotive and aircraft engine oils. Fig. 10 shows the bearing corrosion tendencies of a straight mineral and compounded oil measured under highly accelerated conditions in the MacCoull Tester at 350 degrees Fahr. The same base oil was used in each case. Note that substantial improvements are possible with additives in this connection.

Valve Lubrication

Nearly all American engines today embody automatic valve gear lubrication using engine oil. This feature greatly improves the lubrication of the rocker arm and valve stems, adding to engine reliability and reducing service requirements. With most engines having exhaust valves of austenitic steel, some form of automatic oil lubrication is very desirable to avoid scuffing. Careful control of the rate of oil flow is advisable, as too much oil on the intake valve stem may be undesirable if excessive amounts work down the stem and carbonize on the underside of the head.

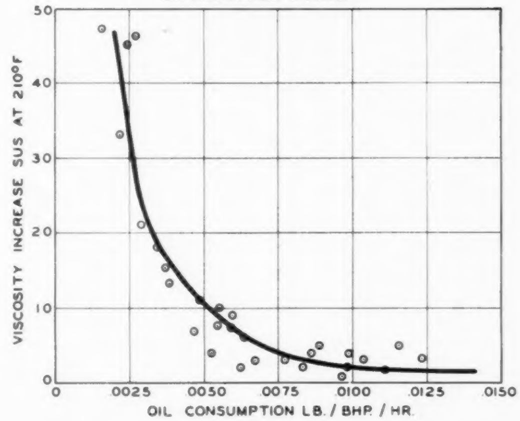


Fig. 9

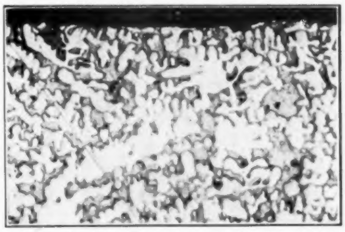


Fig. 8—(a) Photomicrograph of section through new copper lead bearing (coarse grain structure) 150 x magnification. Gray areas represent lead and white areas copper. Crankshaft journal bears against top surface.

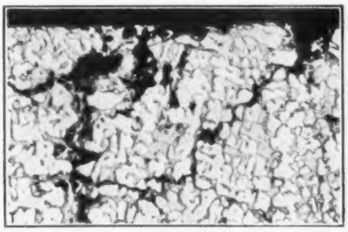


Fig. 8—(b) Similar type of copper lead bearing showing characteristic fatigue type of failure. Note the black broken lines indicating fracture. This is typical of fatigue failure after long periods of severe service.

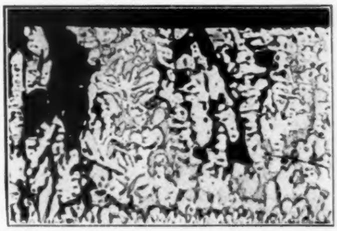


Fig. 8—(c) Copper lead bearing similar to (a) which has corroded. Note the black areas indicating absence of lead Laving a copper matrix.

LUBRICATION

The Lycoming 4-cylinder horizontally opposed engine, 0-145 series (Fig. 11), has a unique method of supplying just the right amount of oil to the rocker box. Oil circulates by gravity through one shroud tube and fills one half of the box up to the center line of the rocker arm bearings, overflowing into the other half and back to the crankcase. Thus the rocker arm is assured of an ample supply and the valve stems are supplied oil by splashing.

The greatest contribution to valve design for high output engines is the sodium cooled exhaust valve originated by Mr. S. D. Heron. Without this improvement it is safe to say that successful high BMEP engines using poppet valves would be doubtful, if not impossible. By using a hollow valve and partly filling with sodium, the heat dissipation properties of the valve are greatly improved. Such valves in aircraft service operate at much lower temperatures than conventional exhaust valves in heavy duty automotive service.

In the sodium cooled valve a greater proportion of heat is carried away from the head through the stem; proportionately less heat passes out via the seat. As one might well expect the transfer of heat to the stem in high output engines has raised the stem temperatures up to approximately 400 to 800 degrees Fahr. Such temperatures obviously impose

RATE OF BEARING CORROSION
WITH CONVENTIONAL AND COMPOUNDED OILS
MAC COULL BEARING CORROSION MACHINE

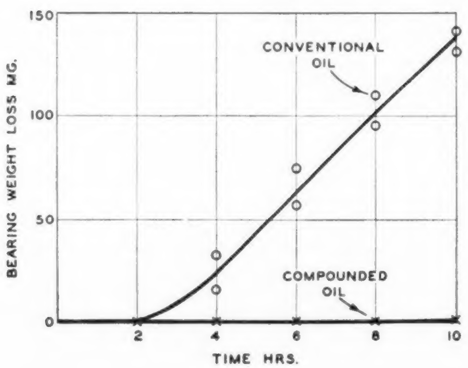
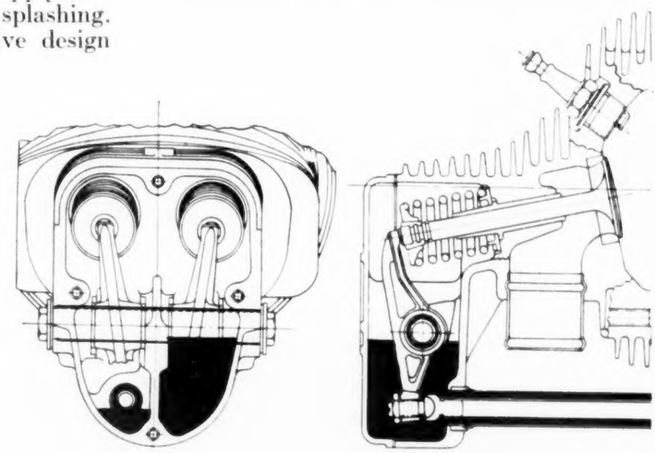


Fig. 10

severe thermal stresses on any oil, especially so around 600-800 degrees Fahr., where any oil will oxidize rapidly leaving a hard glaze-like carbonaceous deposit. The latter is frequently the cause of valve sticking and subsequent valve burning. Controlling the stem temperature and a high rate of oil circulation are desirable; the latter to avoid long exposure of the oil on these hot surfaces. All materials have critical temperature-time limitations which should not be exceeded. Oils being chiefly hydrocarbons have lower critical



Courtesy of Lycoming Division—Aviation Mfg. Corp.

Fig. 11—Sectional views of rocker box in 4 cylinder horizontally opposed Lycoming Engine. The black areas indicate passage of oil in rocker box.

temperature limits than metals such as aluminum or steel.

Consequently, the lubrication of sodium cooled valves has been one of the important phases of aircraft engine oil research. Many prospective oils with ideal piston lubrication qualities could not be released simply because they showed higher valve stem deposits.

Engine builders recognize the importance of carrying off the excess heat from the tip end of the exhaust valve stem. An example of a very well designed rocker box is found on the Pratt & Whitney Twin Wasp Engine (Fig. 13). The exhaust valve stems in these engines are practically as clean after 700 hours as when assembled. In this high output engine we find exhaust valves in airline service with 3000-5000 hours. The oil is supplied to each rocker box in metered amounts through the hollow push rods. The excess oil is scavenged through a circumferential series of tubing inter-connecting each rocker box and running down to a special sump. Meanwhile, some oil drains back through the push rod shrouds or housing in the upper cylinders. The rate of flow to the rocker boxes alone is from 5-7 lb. per minute.

One of the very important features of this design is the provision for cooling the exhaust valve stem. Note that the flow of sodium is blocked off from the tip end. Also note how

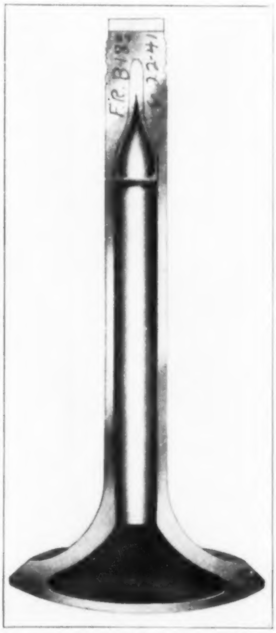
the guide is completely encased in an aluminum boss even to the extension into the box assuring good path for heat flow. In this way the manufacturer avoids excessive stem temperatures, and by good oil circulation the exposure time of the oil is reduced to a minimum.

Sludge

Sludge is the term generally applied to any deposit found within the engine. The popular belief is that sludge invariably comes from oil decomposition. Actually, this is not always the case for such deposits may frequently come from sources other than the lubricating oil. Sludge formations are of three types:

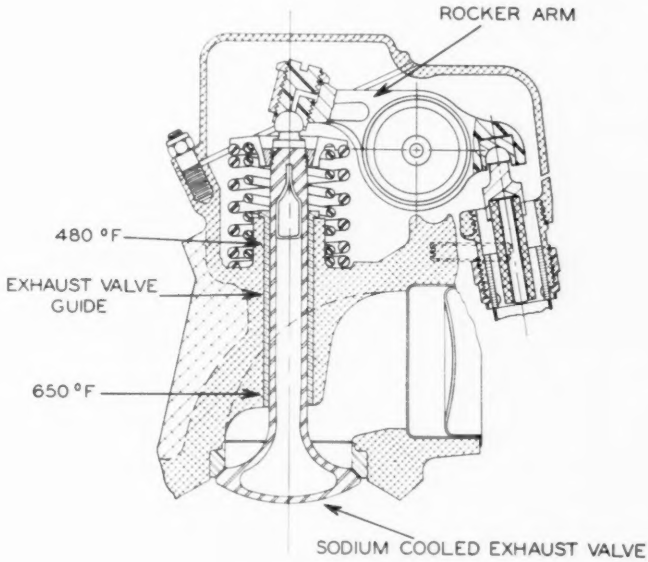
1. Winter type containing water
2. Combustion chamber residues
3. Oil oxidation residues.

One of the most difficult questions to answer is how can water collect in oil used in a high output aircraft engine? Water is one of the principal products which results from burning a hydrocarbon fuel. Since a small percentage of blowby exists in all engines, water vapor finds its way into the crankcase where it condenses on any cool surfaces present. Some of these vapors also find their way into the oil tank. Here, if the temperature is below 120 degrees Fahr. they will condense and emulsify with oil and any foreign material which may be present. Clean oil and water usually do not mix but the reverse is true with oil after only a few hours of service in any engine. Small amounts of water and dirty oil emulsify to form a black pasty material which can clog oil filters, coolers and oil lines.



Courtesy of Thompson Products Corporation

Fig. 12—Section through sodium cooled exhaust valve for Pratt & Whitney Twin Wasp Engine.



SECTION THRU EXHAUST VALVE AND ROCKER BOX PRATT AND WHITNEY TWIN WASP C-3

Courtesy Pratt & Whitney Aircraft

Fig. 13

Airlines find it very important to maintain oil inlet or oil tank temperatures above 140 degrees Fahr. to avoid this condition. Reliance upon automatic oil temperature regulators in the winter time without radiator shutters may make it impossible to keep the oil above 140 degrees Fahr., then severe sludging may follow, so the use of oil radiator shutters is most important during winter operations.

An interesting example of combustion chamber sludge residue is found in crankpin cavity deposits. See Fig. 14. These are composed largely of lead compounds and fuel soot with smaller amounts of oil oxidation products which were centrifuged out and trapped in the crankpin. Similar deposits are also found to a lesser extent in centers of planetary gears. This material is particularly objectionable in crankpins due to the unbalancing effect as well as added possibility of clogging oil jets supplying oil to the pistons. Because the combustion chamber residues can easily be removed by certain types of oil filters, operators will find

it to their advantage to study the effect of filters on their engines.

Sludge from oil oxidation is less prevalent with high quality aircraft engine oils than the other two types of sludge mentioned above. The reason for the general absence of this form of sludge is probably due to excellent engine design and good oil temperature regulation combined with the present high quality of aircraft engine oils. In rare cases deposits arising from oil decomposition are found in limited quantities on pistons or exhaust valve stems which happen to operate at abnormally high temperatures of 600 to 800 degrees Fahr.

Fig. 14—Sludge deposit in crankpin cavity plug of large radial engine.

METHODS OF TEST AND THEIR SIGNIFICANCE

Viscosity

The viscosity test is one of the important tests of an aircraft engine oil. It is a measure of the fluidity or resistance to flow under prescribed conditions. The fundamental expression for this property is absolute viscosity, the unit of which is the poise or centipoise. In commercial practice viscosity may be measured by a variety of instruments and expressed as the time required for a certain quantity to flow through an orifice at a given temperature.

In the United States the standard instrument for testing the viscosity of aircraft engine oils is the Saybolt Universal Viscosimeter (Fig. 15). The Saybolt Universal viscosity at whatever temperature used is time in seconds required for 60 cc's of the oil to flow from the orifice. The temperatures employed for this test are 100, 130 and 210 degrees Fahr. The grade designation for aircraft engine oils 80, 100, 120 and 140 are based upon the viscosity at 210 degrees Fahr. For example, the 120 grade has approximately 120 seconds Saybolt Universal viscosity at 210 degrees Fahr.

In comparing Saybolt Viscosities one should not be misled into the belief that absolute viscosity is proportional to the Saybolt seconds; quite to the contrary, for oils in the range below 200 seconds. This is especially true at the very low viscosities where the deviation between Saybolt and absolute viscosities is so great that the use of Saybolt seconds as an index of absolute viscosity is very deceptive. For example, an oil with a viscosity of 35 seconds Saybolt has about twice the absolute viscosity of one with 32 seconds.

For this reason as well as the need for greater accuracy, there is a definite trend towards the use of the Kinematic procedure as determined in the Ostwald (or modified Ostwald) viscosimeter. This instrument gives values directly in absolute viscosity units as centistokes. A simple conversion can be made from centistokes to poises.

The significance of viscosity is important in that it governs the heat generation, rate of oil flow and amount of friction in a well flooded bearing. The engine designer generally designs his engine for best operation around oils having a definite viscosity. As an example the large radial and in-line engines generally require oils of 120 seconds viscosity whereas the smaller horizontally opposed types use oils of 55-80 seconds Saybolt Universal viscosity at 210 degrees Fahr. For this reason it is necessary to follow the engine builders' recommendation of oil viscosity. To use too low a viscosity in some aircraft engines might involve loss of oil from the bearings at a flow rate faster than the capacity of the oil pump; this might lead to a starved bearing and possible engine failure. Too high a viscosity oil on the other hand, might create excessive friction or overheating, and impair the heat transfer ability through lower rates of flow.

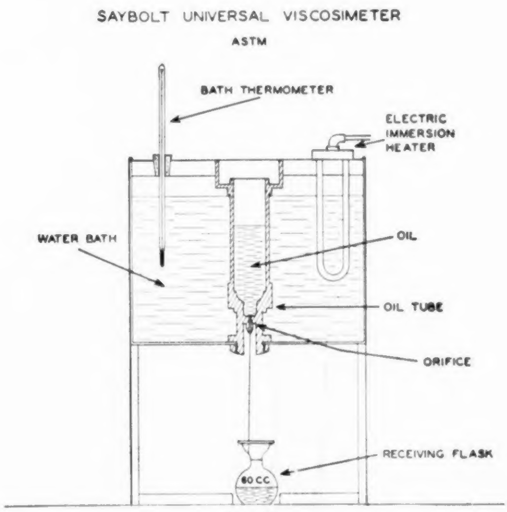


Fig. 15

Viscosity Index-Tentative ASTM Method

The viscosity of all oils changes rapidly with changes in temperature. This rate of change may be conveniently expressed in terms of viscosity index. The scale for viscosity index is based upon the rate of change of viscosity with temperature for certain naphthenic oils which were arbitrarily given a value of 0,

whereas the corresponding characteristics of certain paraffinic oils were given a viscosity index of 100.

Obviously, it is desirable to hold the change in viscosity with temperature as low as it is practical for aircraft engines to allow the use of one oil for wider ranges of temperatures. For example, if we compare the change in viscosity of two oils, one having a V.I. of 100 and the second with a V.I. of 0 both having the same viscosity of 120 seconds at 210 degrees Fahr., we note that the viscosity of each is 1620 and 3838 at 100 degrees Fahr., respectively. Fig. 17. Therefore, a high V.I. oil will have a lower viscosity and create less drag at starting temperature than an oil with a low V.I. Consequently, a moderately high V.I. is desirable to assure easier starting. Most aircraft engine oils for this reason have viscosity indices above 80. This property is also desirable for hydraulic oils in aircraft.

From a practical angle of engine lubrication, viscosity index is no criterion of quality and it has no connection with the ring sticking or stability properties. It should be remembered that there are many outstanding internal combustion engine oils with a V.I. of below 0 as well as many above 100.

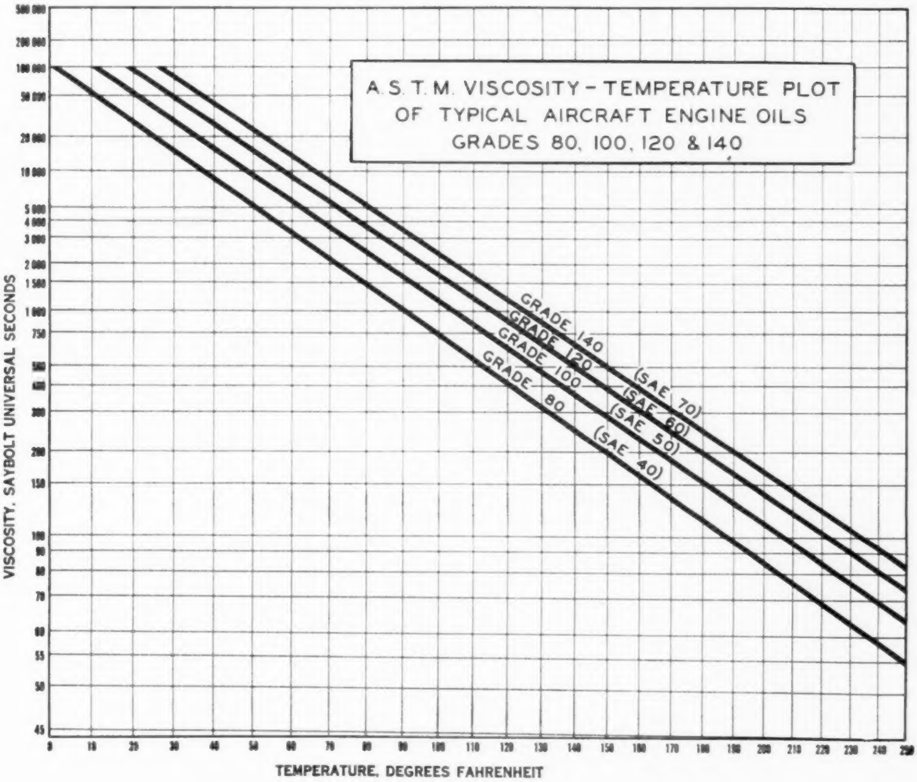


Fig. 16

Flash and Fire Tests

The flash point of an oil is the temperature to which it must be heated in order to give off sufficient vapor to form an inflammable mixture with air. The fire point is the temperature to which the oil must be heated in order to burn continuously after the vapors have been ignited.

The significance of these tests is to indicate the fire hazard of petroleum products. Since the flash and fire points of most well refined aircraft engine oils of grade 120, for example, are above 500 degrees Fahr. and 600 degrees Fahr., respectively, these tests have little value in this connection. Flash and fire point limits are still included in some specifications although the Petroleum Industry has agreed that they have no bearing as a guide to quality.

Carbon Residue—Conradson

The ASTM Standard Method of Test (Conradson-Carbon Residue Fig. 18) requires the rapid or destructive distillation of a given quantity of oil in a specially designed apparatus with air excluded. The residue remaining is expressed in terms of percent of the original sample.

The original purpose of the test was to pro-

vide a means of predicting the amount of carbonaceous residue which might be left within an internal combustion engine. Theoretically, there is an indirect relationship between the values of this test and the extent of engine deposits. Actually, other engine variables such as mixture ratio and operating conditions as well as characteristics of oil itself tend to distort this relationship. The carbon residue test is nevertheless a useful guide to the quality of an aircraft engine oil and it is used without exception in present specifications.

Pour Test

The pour point of an oil is the lowest temperature at which it will pour or flow under a definite set of conditions. The oil to be tested is heated to 115 degrees Fahr. in the standard test jar (Fig. 19) before cooling. At each 5 degree Fahr. drop in temperature during the chilling stage the jar is lifted out of the refrigerated bath and held in a horizontal position for five seconds. The pour point becomes the lowest temperature at which some movement occurs with the jar held in the horizontal position.

The significance of this test is to give some indication of the pumpability of the oil in service. It should be noted here that the nature of the oil system, size of lines, and head

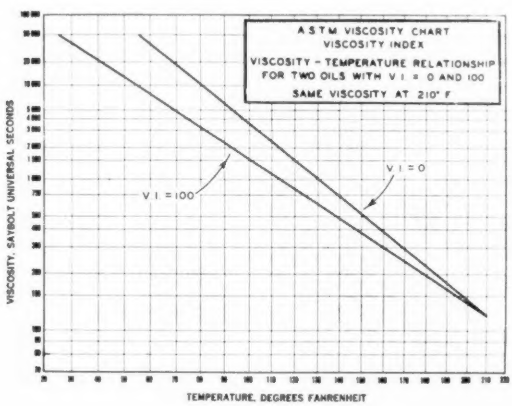


Fig. 17

as exerted by the quantity of oil in the tank affect the pumpability. For these reasons it is frequently noticed that an oil having a plus 15 degrees Fahr. pour point may be pumped at plus 5 degrees Fahr. In addition to the above factors it should be noted that the pumpability is also affected by whether the pour point was due to solidification of wax (waxy pour), or due to the very high viscosity (viscosity pour).

The pour point test is very important and should be included in all aircraft engine oil specifications.

Emulsion

The emulsion or demulsibility test for aircraft engine oils consists in paddling 40 ml. of oil and 40 ml. of distilled water at 180 degrees Fahr. for a specified period and then noting the time for separation following this agitation. The separation generally is complete after 15 minutes with highly refined straight mineral

CARBON RESIDUE - CONRADSON

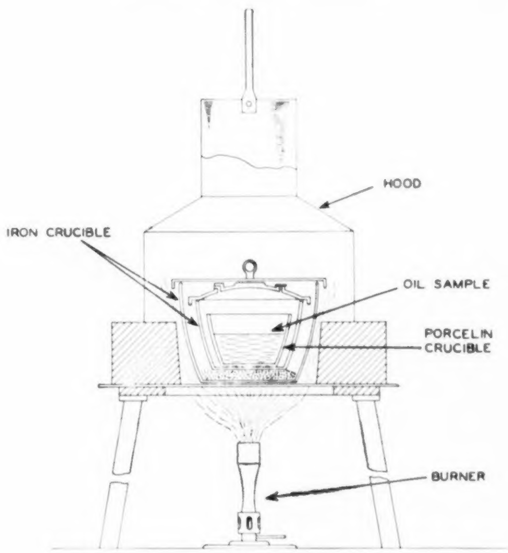


Fig. 18

types of oils. A 1% salt water solution is sometimes specified in place of distilled water using the same conditions of temperature.

For steam turbine oils good separation from water or good demulsibility is very desirable. For aircraft engine oils as well as for motor oils, there is some doubt about the value of emulsion tests. This test can be used as a guide to quality but it has a definite disadvantage in that it prevents the use of many additives which are extremely effective in improving aircraft engine oils. In fact, this test can be the means of throttling future developments in this field. For this reason, those companies which recognize the restrictive aspects of this test have deleted it from their lubricant specifications. From a practical standpoint any oil after 5 or 10 hours of use in the average engine has collected enough foreign material to prevent the oil from passing the emulsion tests. Therefore, a majority of the operating life of any internal combustion engine is with an oil which does not pass the emulsion test.

The general idea of emulsification should not be abandoned entirely, but judging from present aircraft operating conditions some sort of a foaming test might be desirable.

MacCoull Bearing Corrosion Test—Description of Apparatus

A great many oxidation and bearing corrosion tests have been devised during the past ten years but none has been accepted as a standard at this time. Perhaps, the chief reason against their standardization has been the lack of correlation with full scale engine results. The MacCoull Machine (Fig. 20) is showing some very interesting correlation with engine tests and is successfully used by a number of companies. The present machine was designed three years ago by Pratt & Whitney Aircraft using the principle of The Texas Company's original Whirligig Corrosion Tester.

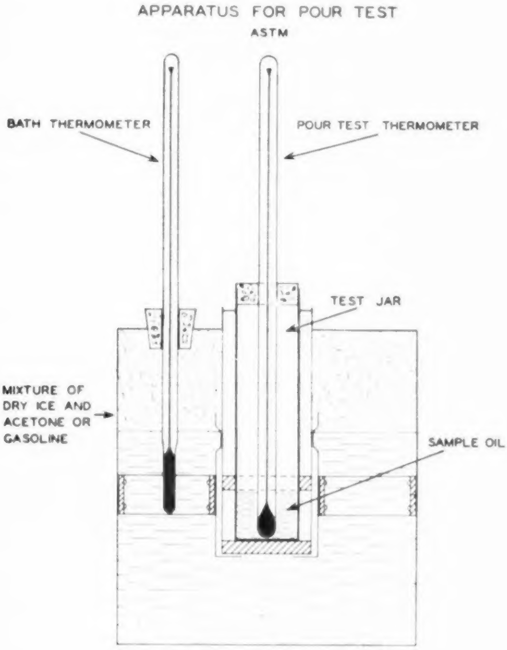


Fig. 19

The present MacCoull machine consists of a test bearing, usually copper-lead, inserted at the neck of an inverted hollow conical spinner. The latter is partially immersed in 125 cc's of oil sample in a glass beaker, and the continuous rotation of the spinner at 3000 r.p.m. circulates oil up through the bearing and out the top where it sprays against the side of the beaker and mixes with air to promote oxidation. At intervals of every two hours the test bearing is removed and weighed to determine the weight loss up to the conclusion of the test at 10 hours. The weight loss data may be plotted giving curves similar to Figs. 7 and 10. For new oils (unused) the temperature is usually maintained at 350 degrees Fahr. whereas used oils are sometimes tested at 250 degrees Fahr.

Significance of the MacCoull Test

The MacCoull Bearing Corrosion Test has become a most useful method of comparing the corrosive tendencies of any number of oils; it is also a good oxidation test. As a bearing corrosion test it incorporates such conditions as: agitation of oil and air to promote oxidation, a definite rate of oil flow over the test bearings, means of preventing metal to metal contact between the bearing and shaft, and a catalyst to accelerate the rate of oxidation. Some of the other advantages of this test are: results are obtained quickly (10 hours), small sample required, i.e., 125 cc's, the cost for each run is comparatively low and it correlates quite well with full scale accelerated engine tests.

Since the corrosion rate also depends upon the nature of the bearing, it is sometimes difficult to compare actual values obtained with different oils and different batches of copper lead bearings. To minimize this variable it is customary to order at least a year's supply of test bearings made in one batch. Another possibility of reducing the effect of varying compositions in copper-lead bearings may be to use pure lead by electroplating.

As mentioned above, the corrosive values are relative and will aid in deciding whether one oil is more corrosive than another. It will not necessarily tell whether a certain oil will corrode the bearings in a given engine unless the oxidation tendencies of the engine are also known. In other words, since the oxidation rate depends chiefly upon oil temperature and oil consumption (time), it resolves into a question of how severe are the engine conditions. For this reason an oil found satisfactory in one engine may not be so in another.

Selection of Aircraft Engine Oils

Specifications covering the customary physical tests do not constitute a reliable basis of selecting an aircraft engine oil. It is true that the ASTM tests for viscosity, viscosity index, pour and carbon residue serve as a useful guide in the preliminary selection of an oil, while the other accepted tests of gravity, flash, fire neutralization number, precipitation number, or emulsion, are almost useless in judging the quality of aircraft engine oils made by reputable refiners.

Oxidation tests are helpful in predicting sludging and varnish forming tendencies, but may give misleading values of ring sticking and bearing corrosion. A combined oxidation and bearing corrosion test such as the MacCoull Test offers interesting possibilities in evaluation of aircraft engine oils for resistance to

sludging and tendency towards corrosion of bearings.

The only reliable method of evaluating an oil with respect to its ability to prevent ring scuffing, ring sticking, varnish, cylinder wear, is by a full scale engine test. This test also provides a fairly good indication of sludging resistance, bearing corrosion, carbon deposits and oil consumption. Of course, the greatest advantage in a full scale engine test is that it furnishes unquestionable evidence of the suitability of an oil in all respects in that particular engine.

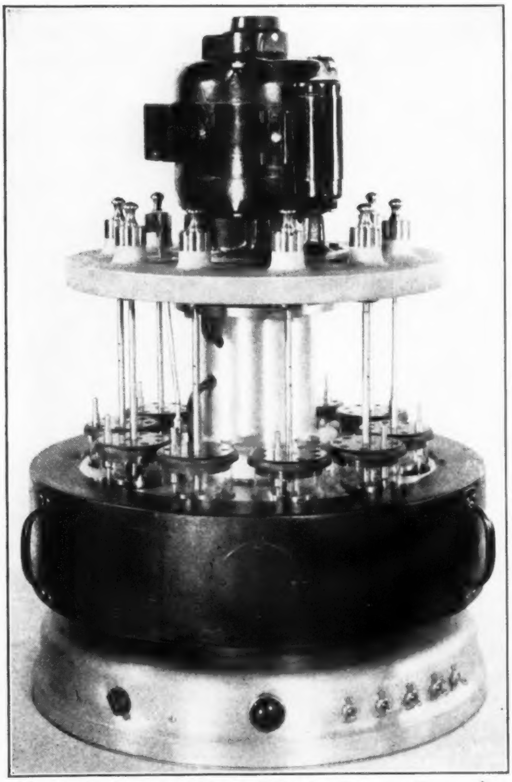


Fig. 20—Photograph of MacCoull Bearing Corrosion Tester. Note ten separate beakers. The spinner in each is driven by one electric motor.

For these reasons manufacturers of high output aircraft engines are placing more and more emphasis upon full scale tests than upon oil specifications. The test period is usually of 50-60 hours duration at rated power on the test stand, but the most conclusive test is actual use of an oil in airline operation for periods of 600-700 hours.

SUMMARY

It has been the purpose of this issue to discuss the close relationship between engine design, maintenance and operating technique upon lubrication of the high output aircraft engine. Because of the complexity of this subject only a few of the more important factors could be included herein, so the foregoing is by no means complete. It may be added here that as specific power outputs continue their upward trend more and more attention will be necessary to control temperatures of various engine parts so that the lubricant may function most efficiently.

The results of most recent research work with aircraft engine oils indicates that the greatest improvements within the next few years may be found through use of additives or compounds rather than by improvements in the base oil itself. Already there are developments under way which show great promise of improving engine cleanliness and which may allow extensions in present overhaul periods on existing engines. It should be stressed, however, that new developments in these oils are sometimes far more difficult to make than changes in engine design. Because one oil must give the optimum lubrication to all parts of the engine, be it rings, cylinders, bearings, gears, valves, etc., a greater balance of properties is often necessary than in the design of engine parts. Therefore, an extensive program of research work is frequently required before a new aircraft engine oil can be developed. For this reason changes must necessarily be made more slowly.

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TEXACO RECOMMENDATION CHART

FUELS AND LUBRICANTS FOR AIRCRAFT ENGINES

KEY TO GRADES

(Lubricating Oil Only)

Chart Symbol		Chart Symbol	
40	Texaco Aircraft Engine Oil S.A.E. 20	100	Texaco Aircraft Engine Oil S.A.E. 50
60	Texaco Aircraft Engine Oil S.A.E. 30	120	Texaco Aircraft Engine Oil S.A.E. 60
80	Texaco Aircraft Engine Oil S.A.E. 40	120-G	Texaco Aircraft Engine Oil S.A.E. 60

140 Texaco Aircraft Engine Oil S.A.E. 70

NAME AND MODEL	Min. Fuel Octane Rating (AFD 1-C)	Lubricating Oil		
		Above 75° F.	Lowest Expected Temperatures	
			32° F.	0° F.
AERONCA—E-113C (Aero. Corp. of Amer.)	73	120	100 / 80	60
ALLISON—V-1710-C	100	120	120	100
CONTINENTAL				
A-40-4 (No. 2624 and up)	73	80	80	60
A-40-5 (No. 3231 and up)	73	80	80	60
A-40-4 (before No. 2624)	73	60	40	40
A-40-5 (before No. 3231)	73	60	40	60
A-50, A-65, A-75	73	80	80	60
A-70	73	100	80	80
A-80	80	80	80	60
R-670, W-670-K and K-1	73	120	100	80
W-670-M and M-1	80	120	100	80
FRANKLIN (Air-Cooled Motors Corp.)				
4AC-150, 4AC-150A, 4AC-171	73	80	80	40
4AC-176 †6.3	73	40	40	40
†7.0	80	40	40	40
4AC-199	80	40	40	40
6AC-264 †6.3	73	40	40	40
†7.0	80	40	40	40
FUNK (Akron Aircraft) E	73	60	40	40
GUIBERSON DIESEL	445 Diesel Chief	120	120	100
JACOBS L-4 & L-5 Series	73	120	100	80
L-6 Series	80	120	100	80
KEN ROYCE (Rearwin Aircraft & Engine Co.), 5-E, 5-F, 7-F	73	120	100	80
KINNER K-5, B-5, R-5, C-5, C-7, SC-7A	73	120	100	80
LAMBERT (Monocoupe Corp.)	73	80	60	60
LE BLOND (Rearwin Airc. & Eng. Co.)	73	100	100	80
LENAPE LM-3, LM-365, LM-375, LM-5	73	120	100	100
LYCOMING (Aviation Mfg. Corp.)				
O-145-A	73	60	60	40
O-145-B	73	80	60	60
O-145-C, GO-145-C	73	80	60	60
R-530-D2, R-680-B4C, R-680-D6, R-680-E2	73	120	100	80
LYCOMING (Cont.)				
R-530-D1, R-680-D5, R-680-E1	80	120	100	80
R-680-E3	88	120	100	80
MENASCO, M-50	73	80	60	60
B-4, B-6, C-4, D-4	73	120	100	80
B-6S, C-4S	80	120	100	80
C-6S-4	88	120	100	80
PRATT & WHITNEY				
Wasp Jr.	*88	120	100	100
Wasp	*88	120	100	[illegible]
Twin Wasp SC3-G	88	120	100	100
Twin Wasp S1C3-G, S4C4-G	[illegible]	120	100	100
Twin Wasp S3C4-G	100	120	100	100
Double Wasp	100	120	100	100
Hornet (T2E only)	80	120	100	100
Hornet (Other Models)	88	120	100	100
RANGER				
6-390 B & D, 6-440C-2 & C-3	73	120	100	100
6-410 B-1, 2, 3, 6-440 C-4	80	120	100	100
6-440 C-5	88	120	100	100
SKYMOTOR, 70-A	73	60	60	40
WARNER				
Scarab 29, 30, 40, 50	73	120	100	80
Scarab Jr. 50	73	120	100	80
Super Scarab 40, 50, 165	73	120	100	80
WRIGHT				
Whirlwind R-540, R-760, R-975	**	120 or 120-G		
Cyclone F Series	**	120 or 120-G		
Cyclone G, G-100, G-200 Series	**	120-G		
Double Row Cyclone GR-2600 Series	**	120-G		
Double Row Cyclone GR-3300 Series	**	120-G		

† Compression Ratio.
* Some models are rated on 80 octane fuel for operation not in excess of normal rated power and R.P.M.
** Refer to name plate on nose section of engine for minimum fuel octane rating.
NOTE: Temperature limits for lubricating oil recommendations refer to atmospheric temperatures.

GENERAL LUBRICATION RECOMMENDATIONS FOR AIRCRAFT ENGINE ACCESSORIES AND AIRPLANES

Rocker Boxes (Grease Lubricated)	Texaco Marfak No. 2 or No. 3
Magneto, Starter and Generator Bearings	
Oil Lubricated	Havoline or Texaco Motor Oil S.A.E. 20
Grease Lubricated	Texaco Starfak Grease No. 2
Wheel Bearings	Texaco Starfak Grease No. 2 or No. 3; Texaco Marfak No. 2 or No. 3
Landing Gear Fittings	Texaco Marfak No. 0, 1, or 2
Controllable Pitch Propellers	
Grease Lubricated	Texaco Propeller Lubricant No. 00
Electric Propellers	
Speed Reducer	Texaco Capella Oil AA
Hub Mechanism	Texaco Propeller Lubricant No. 00
Retractable Landing Gear (For hydraulic fluid where mineral oil is recommended)	
Winter	Texaco Rabtex Oil
Summer	Texaco Spica Oil; Texaco Capella Oil


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BE A U. S. ARMY
FLYING CADET